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TECHNICAL PROGRESS REPORT

Bell Report No. 60007-031

Quarterly Report

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

CA

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Bell Aerospace Corporation

Bell Aerosystems Company

Cleveland, Ohio 44103

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ABSTRACT

During this reporting period one accelerometer has entered into the thermal sterilization period. Another has been readied to initial testing prior to sterilization. The other accelerometers are nearing completion. Preliminary test results indicate excellent scale factor stability. All accelerometers contain pendulums cured at 300°F to increase the Heat Distortion Temperature of the spring joint epoxy to 370°F which should reduce the null bias shifting.

The techniques of Laser beam welding the proofmass assembly were developed in three basic steps. Welding schedules were established from test results of welded specimens. The first two proofmass assemblies to be welded by the Laser method are experimental vehicles in the effort to isolate the source of null bias shifts observed on a standard Model VII instrument after exposure to sterilization temperature. Modifications of the design will be necessary to reduce the constrainment current from approximately 100 ma.

The design of the transformerless pickoff electronics has demonstrated superior performance in electrical null stability. The improvement can be attributed to the FET input capacitances, which are more stable than the stray capacitances of a hand wound transformer.

As reported in the last quarterly report of August 15, 1968, there were two potential contributors to the observed null bias shift on accelerometer serial number 0656: the stresses produced in the spring and the epoxy joint due to the thermal expansion differential of the proofmass and the baseplate, and insufficient curing of the spring joint epoxy. Since a re-design of the pendulum assembly was not within the scope of the present contract, an effort was made to improve the epoxy spring joint.

At Bell's suggestion, the Ablestik Adhesive Company tested their Ablecast 147-1 frozen epoxy to determine the Heat Distortion Temperature (HDT) when it is cured at 300°F for extended periods. Testing was conducted according to ASTM procedure D-648-56 and results are reported below.

Days at 300°F	HDT
2	372°F
4	378°F
8	378°F

While waiting for these test results, the built and tested pendulums were recured at 300°F for 60 hours. It was assumed and verified above that this would yield an HDT of about 370°F.

Recuring was performed in an oven containing inert nitrogen gas to minimize any possible oxidation or discoloration of the parts. Since these pendulums were not removed from their respective mechanical assemblies, the epoxy spring joints were recured with the pendulous axis vertical ("gate" position), thus one 'g' stresses typical of this mode of storage were present. On new and rebuilt pendulums, the spring joint epoxy will be cured at 300°F for 60 hours in an inert nitrogen atmosphere after the required two hour jelling period at 200°F. Curing will take place on the building fixture which assures stress free conditions.

Due to the caution applied during the recuring, there was no discoloration or other visible evidence of oxidation on critical components. Also, test results indicate no pattern of degradation of null bias sensitivity with temperature.

Bell Ident No.	After 250°F Cure bias drift with temp	Comment	After 300°F Cure bias drift with temp
J4	-1.48 ug/°F	recured	-3.71 ug/°F
J5	no readings	recured	-7.6 ug/°F
J6	no readings	recured	3.59 ug/°F
J3	high input axis misalignment	rebuilt	-2.53 ug/°F
J3	13.0 ug/°F	recured but will be rebuilt	no readings

In order to assure scale factor stability after exposure of the instrument to the sterilization cycle, the pendulums were outgassed at 160°F for 120 hours at a pressure of less than 50 microns. This would practically eliminate any future pendulum weight losses which could severely influence scale factor stability. Prior to hermetic sealing, the instrument is vacuum baked at 140°F for 4 hours to remove all moisture and water vapor which can adversely affect null bias and/or scale factor. The sealed accelerometer contains only dry inert gases.

Problems encountered in manufacturing transformers were lead breakage and internal electrical shorting. These were basically the result of workmanship errors and have been resolved by furnishing additional instructions and work aids to the assemblers.

Other than the transformer difficulties, the manufacturing phases have progressed without incident up to and including the sealing of the accelerometers. During the initial testing period, the instrument has performed satisfactorily and especially well in scale factor stability. In order to gain a better understanding of the effects of thermal sterilization on instrument performance, a parameter check is being introduced after each of the 6 cycles in the first sterilization period. These parameter checks include null bias and scale factor measurements at room and elevated temperature of 176°F (80°C) (Table 1). It is interesting to note that, while null bias shifts of larger magnitude occurred, the scale factor remained free of excessive changes.

MECHANICAL UNIT S/N 4 JPL STERILIZATION TESTING

TEMPERATURE RUN 1

INITIAL TESTING

T(I)	V90(I)	V270(I)	SF(I)	MA/G	B(UG)	RPM/F	B(UG/F)
72.18	1.045437	-1.045707	1.045571	0.995782	-129.1	0.0	0.0
121.64	1.050830	-1.051550	1.051190	1.001132	-342.5	109.2	-4.3
148.91	1.053823	-1.054872	1.054347	1.004140	-497.0	111.1	-5.7
177.44	1.057076	-1.058451	1.057763	1.007393	-649.6	114.9	-5.3
72.75	1.045580	-1.045870	1.045725	0.995928	-138.6	108.7	-4.9
123.04	1.051020	-1.051804	1.051412	1.001344	-372.8	108.7	-4.7
148.42	1.053842	-1.054879	1.054360	1.004152	-492.1	111.4	-4.7
176.45	1.057010	-1.058370	1.057690	1.007323	-642.9	114.0	-5.4
71.78	1.045477	-1.045747	1.045611	0.995820	-129.1	109.1	-4.9
122.92	1.050997	-1.051783	1.051390	1.001323	-373.7	108.6	-4.8
149.09	1.053869	-1.054943	1.054406	1.004196	-509.2	110.5	-5.2
175.96	1.056910	-1.058271	1.057590	1.007229	-643.8	113.7	-5.0
71.78	1.045500	-1.045788	1.045644	0.995851	-137.7	108.4	-4.9
121.78	1.050843	-1.051661	1.051252	1.001192	-389.2	107.8	-5.0
149.81	1.053975	-1.055045	1.054510	1.004294	-507.4	111.5	-4.2
177.04	1.057032	-1.058415	1.057723	1.007355	-654.1	113.2	-5.4
71.38	1.045447	-1.045733	1.045590	0.995800	-136.8	108.5	-4.9
121.57	1.050858	-1.051649	1.051253	1.001193	-376.5	108.5	-4.8
148.89	1.053849	-1.054915	1.054382	1.004173	-505.6	109.8	-4.7
175.96	1.056908	-1.058284	1.057595	1.007233	-650.6	113.9	-5.4
72.09	1.045506	-1.045806	1.045655	0.995862	-143.6	108.7	-4.9
121.78	1.050881	-1.051647	1.051264	1.001203	-364.2	108.5	-4.4
149.00	1.053869	-1.054946	1.054407	1.004197	-510.6	110.7	-5.4
175.21	1.056783	-1.058165	1.057473	1.007117	-653.4	112.2	-5.4

PARAMETER CHECKS AFTER EACH STERILIZATION CYCLE

T(I)	V90(I)	V270(I)	SF(I)	MA/G	B(UG)	RPM/F	B(UG/F)
75.38	1.045371	-1.047323	1.046347	0.996520	-932.9	105.4	2.8
176.07	1.056179	-1.058915	1.057547	1.007187	-1293.6	107.5	-3.6
76.50	1.045223	-1.047299	1.046261	0.996439	-992.2	107.2	-3.0
175.50	1.056299	-1.058955	1.057627	1.007263	-1255.6	111.0	-2.7
76.86	1.046508	-1.045941	1.046225	0.996404	270.7	109.3	-15.5
175.82	1.057446	-1.057721	1.057583	1.007221	-130.3	110.9	-4.1

Table 1

LASER WELDING

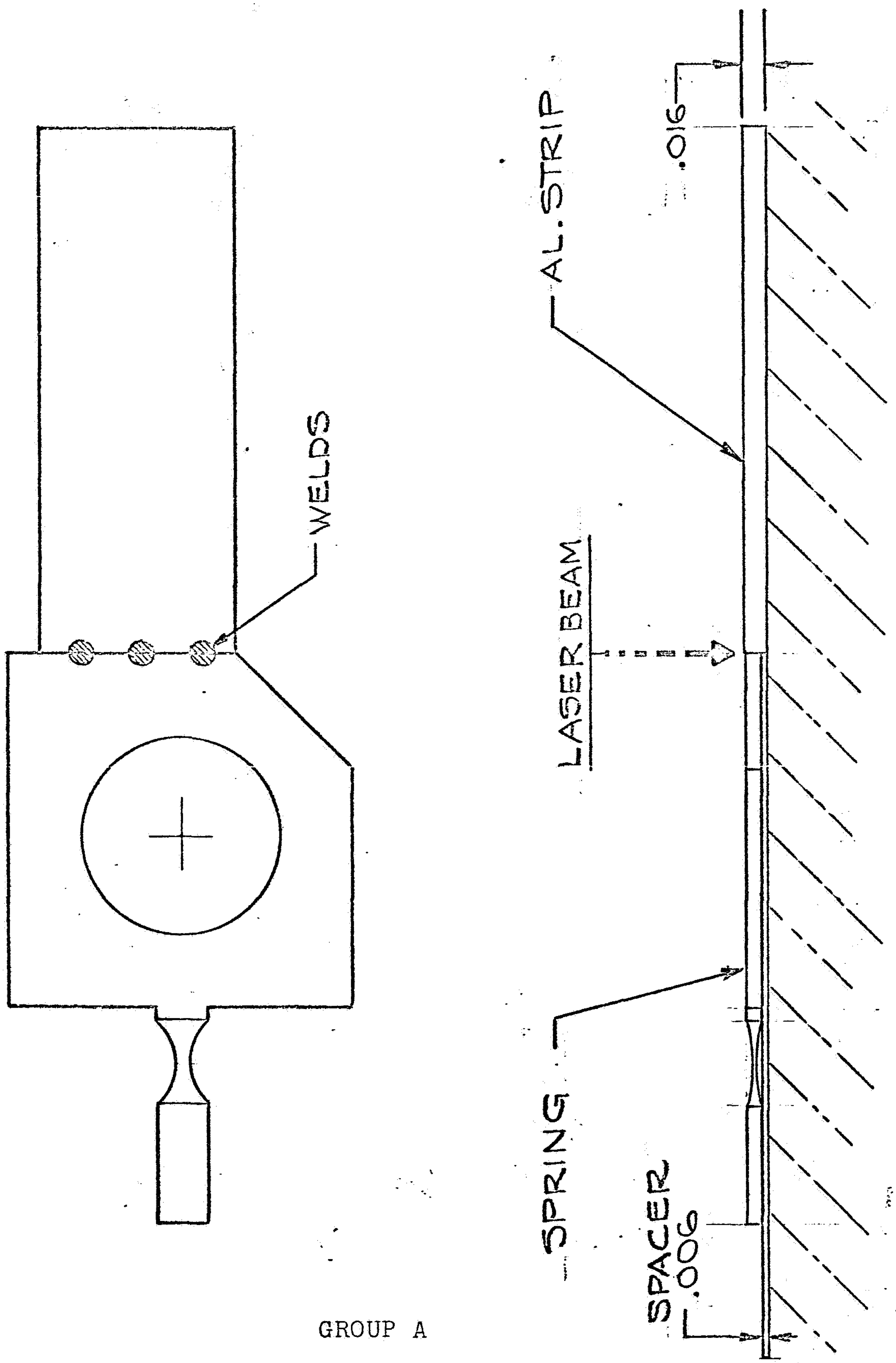
The Laser Systems Corporation in Ann Arbor, Michigan, provided their equipment and technical assistance to perform the Laser welding on the proofmass assemblies. This company was chosen since the equipment in their application laboratory seemed to be satisfactory for our needs as their field is mainly technical welding (including that of beryllium copper), and also cutting.

The equipment used at the Laser Systems Corporation to weld the test samples was their standard type LW 212 Laser head containing a Neodymium doped glass rod for producing the Laser beam. The Laser equipment is coupled with a modified Nikon comparator. The advantageous feature of the comparator is that the alignment of the object to be welded and the Laser beam can be easily accomplished. The accuracy of adjustment and repeatability is better than .001 inch.

The energy level can be adjusted in fine steps to a maximum of 90 joule output and the pulse duration in steps of 1 millisecond to a maximum of 6 milliseconds. The energy needed to create a weld spot of .012 to .015 inch in diameter for a beryllium copper-aluminum joint was found to be between 5 and 15 joule. The lower value is adequate when a 20 times magnifaction lens is employed while the higher value is necessary with a 10 times magnification lens. This equipment also allows enough room for fixturing since the distance between the objective lens and the weld spot is about 1.3 inches when optical system with 20 magnification is used. Under 10 times magnification, this distance becomes 2.6 inches.

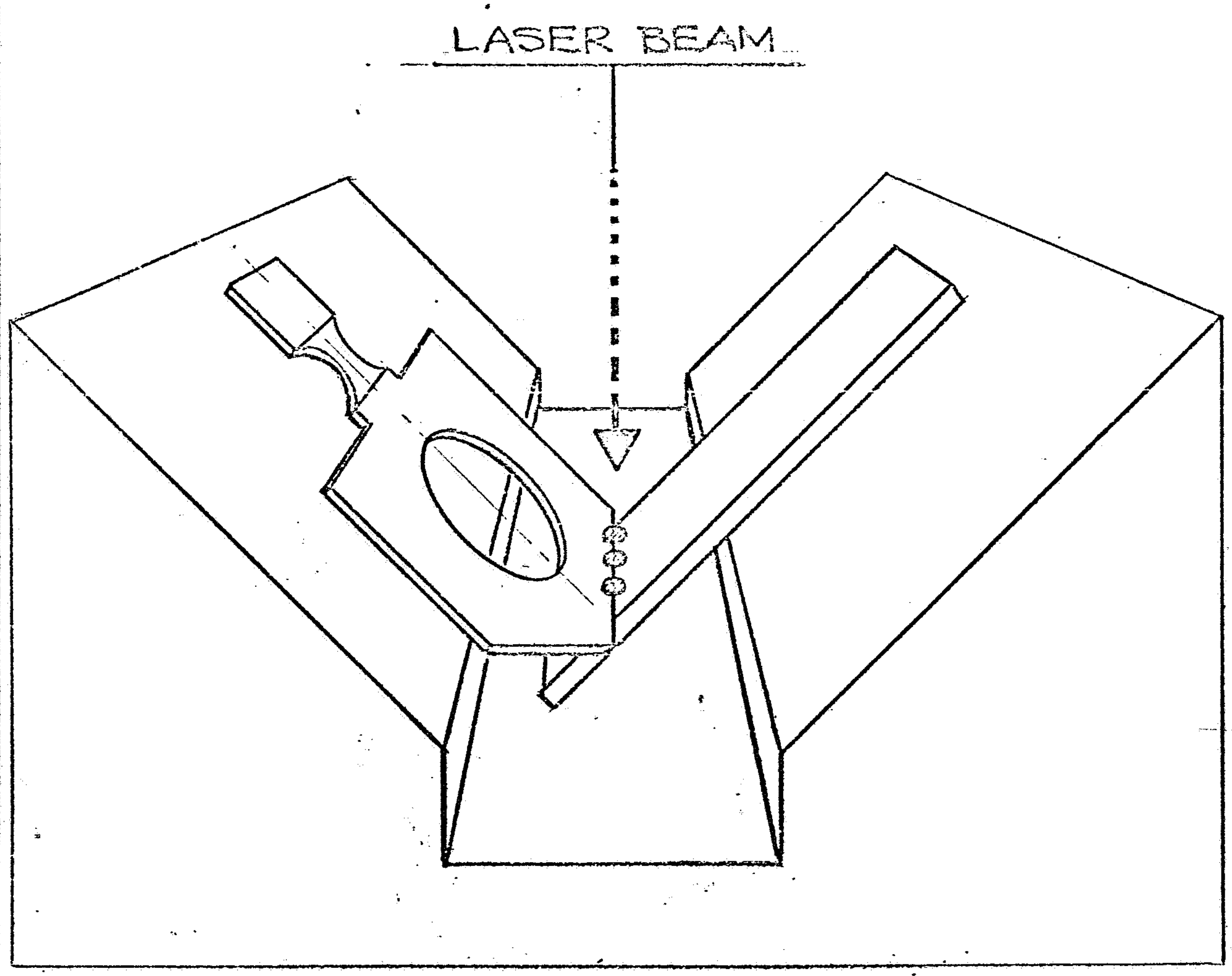
Laser welding of the proofmass assemblies is being approached in three steps in order to better evaluate this method of joining. The first step is to perform a simple butt weld between .016 thick aluminum and .010 thick beryllium copper strips. These materials are the same as presently used for the support and the spring. Details of this Group A weld set up are shown in Figure 1. Since the support and spring are in two perpendicular planes, the aluminum and beryllium copper parts were aligned in a 'V' block for the second welding experiment. Figure 2 depicts these Group B welds. A third group C was established which would simulate the actual conditions under which the welds would be made. Figures 3 and 4 show these configurations.

Sample items 1 and 2 of Group A were used to set up the equipment and to determine the proper energy level needed to produce a good weld spot on the line joining the aluminum and beryllium copper parts. The energy was varied between .4 and 8 joules using the 20 power lens. A 5 joule energy and a 2 millisecond pulse length resulted in a usable weld spot of approximately .012 inch diameter. To evaluate the weld strength produced by different energy level settings, sample items 3, 4, and 5 of the same group were welded by applying 5, 7 and 2.5 joules respectively. Three weld spots were produced with their centers



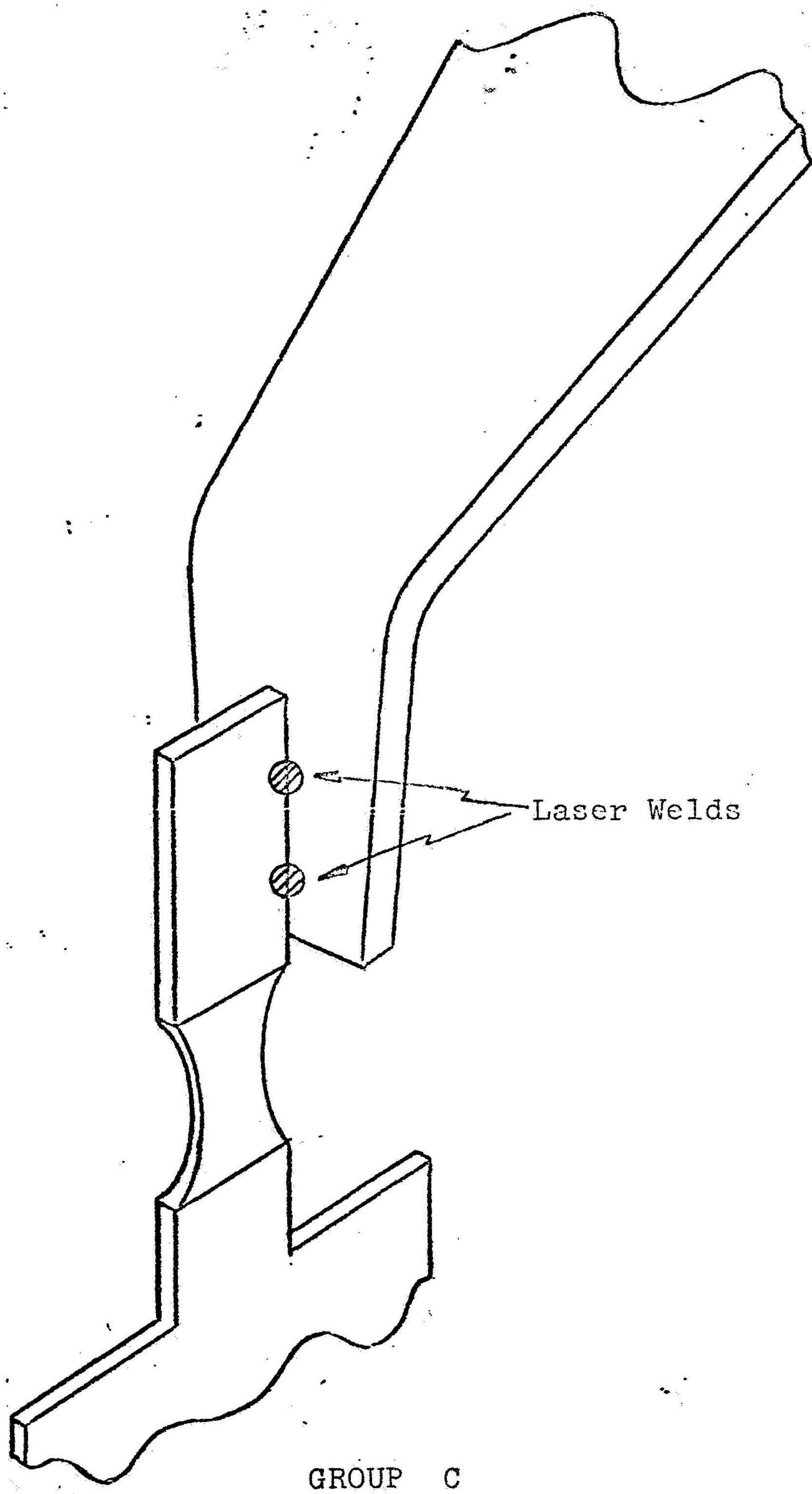
GROUP A

Figure 1



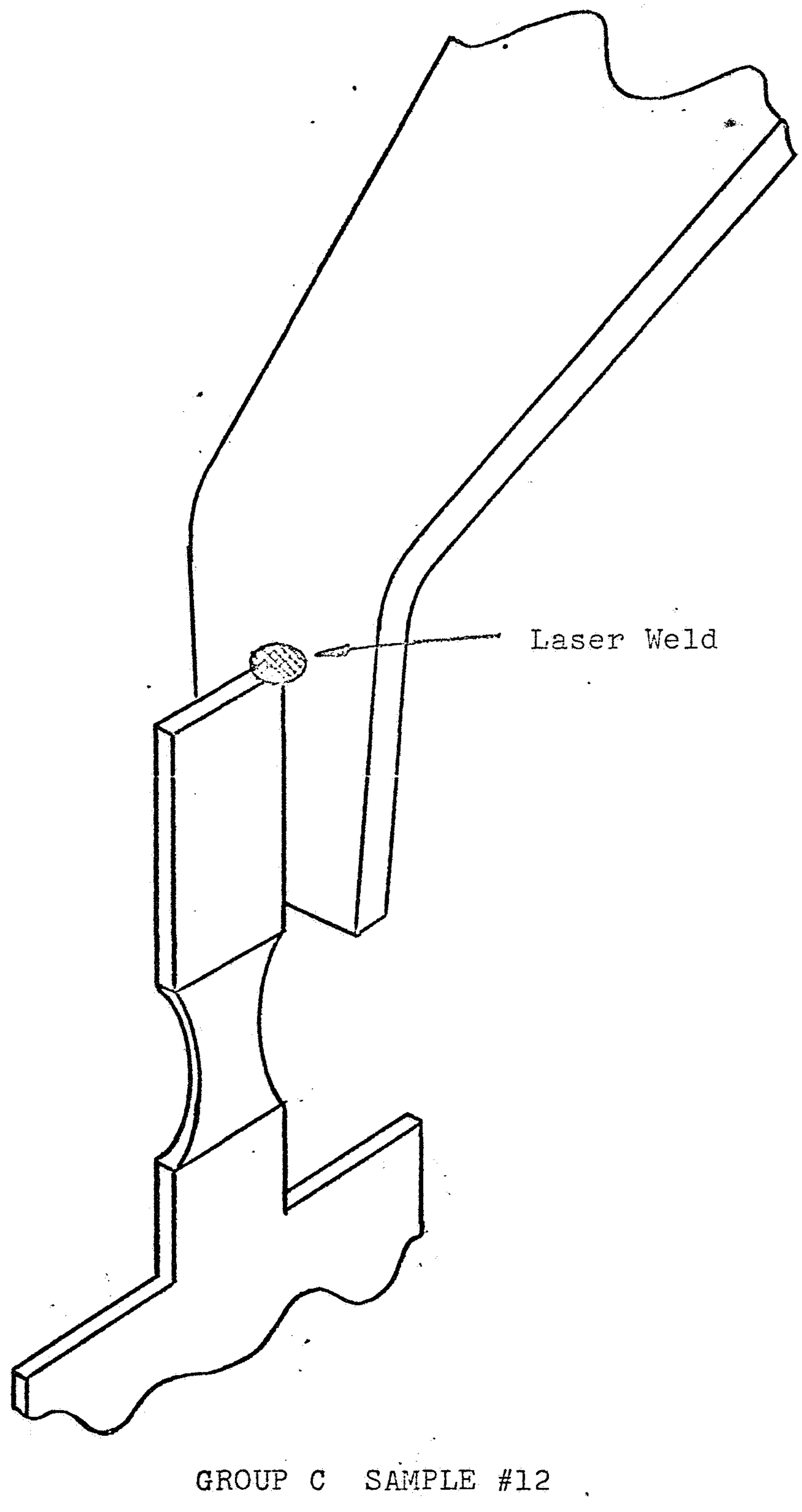
GROUP B

Figure 2



GROUP C

Figure 3



GROUP C SAMPLE #12

Figure 4

on the joint line of the two materials. Since the beryllium copper requires more heat for melting than the aluminum, it was felt that by offsetting the Laser weld spot to transmit more energy into the beryllium copper material, a better joint would result. Sample 6 was thus welded by applying 5 joules and the weld spot center was moved .003 inch from the joint line toward the beryllium copper material.

Weld samples 7 and 8 are of Group B and each was joined with three weld spots using 5 joules and 20 power magnification. Sample 7 was welded on the joint line while sample 8 had the weld spots shifted .003 inch toward the beryllium copper material.

Group C contains samples 9, 10, 11 and 13. Two weld spots were produced at the corner between the spring tab and the pendulum support as shown in Figure 3. In all cases the energy level was adjusted for 5 joules and the magnification at 20 power. Items 9, 10 and 13 had the spring tab secured with epoxy to prevent movement of the aligned parts during welding. Specimen 11 was intentionally welded without epoxy aid. On sample 9, the weld spots were offset toward the spring material. Sample number 12 was provided with one weld spot located at the upper corner of the spring tab (Figure 4). No epoxy had been used to secure the spring tab. Since the fixturing in this case required a working distance of more than the 1.3 inches allowed by the optical system of 20 times magnification, the optical head of 10 power magnification was employed, necessitating an increase of the output energy. An energy level of 15 joules was used.

The welds using 2.5 joules on sample 5 were found to be inadequate. This sample broke while being removed from the epoxy glass board for the pull tests. Samples 9 and 11 were not welded together. It is surmised that, since item 11 did not have the spring tab secured with epoxy, there was a sudden motion of the spring tab during the solidification of the weld material. Although item 9 did have the spring tab secured, it is felt that the gap between the spring and the support was misaligned and was greater than the .001 inch allowed.

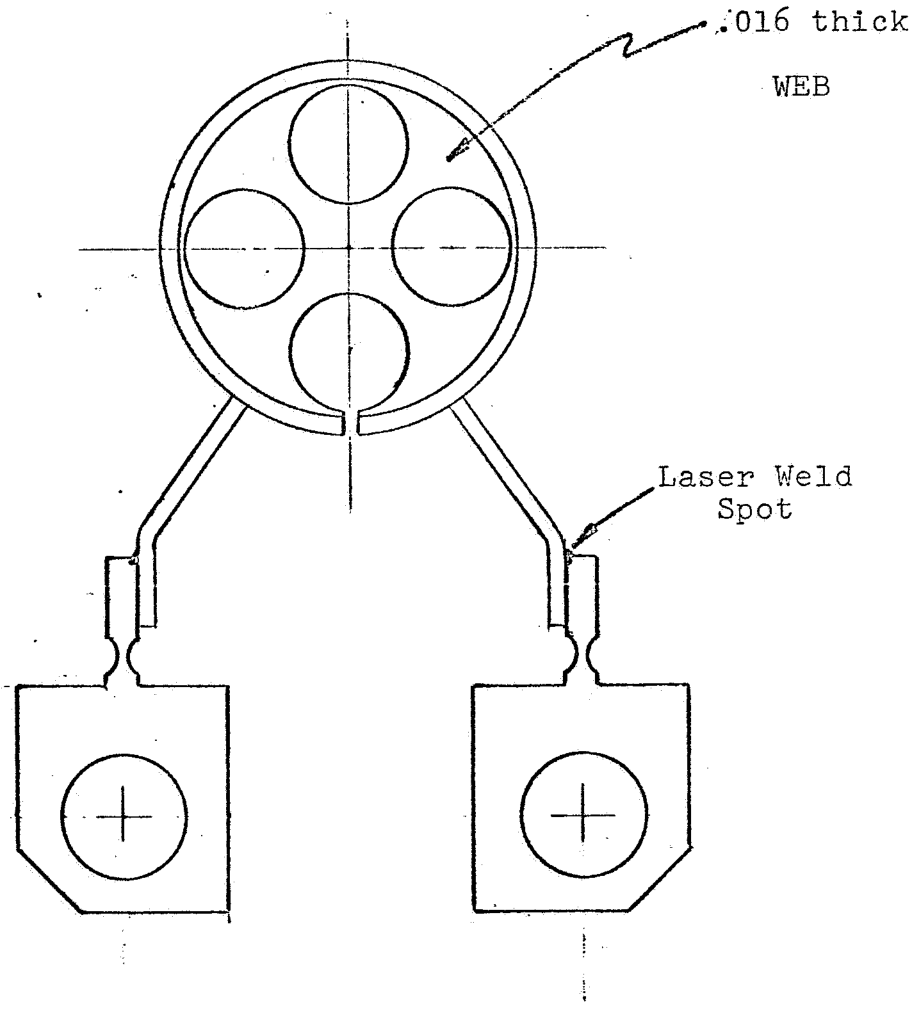
An effort was made to obtain information on stresses which may have been introduced in the joint between the two metals caused by the contraction during the solidification of the weld spots. The screws holding the springs on samples 10, 12 and 13 were carefully removed and the lift of the spring body off of the insulator was observed. It was evident that sample 12 was the one least influenced.

Test samples 1, 3, 4, and 6 were subjected to a pull test in order to determine the strength of the weld. For this purpose these samples were carefully removed from the epoxy glass board. The samples were attached to a fixture in such a manner that bending was avoided during the pull test. Generally, all samples separated on the aluminum side of the weld spot.

Sample No.	Rupture Load	No. of Weld Spots	energy (joules)	Location Weld Spot	Strength per Weld Spot
1	43 oz.	5	.4 to 8	Joint line	8.6 oz.
3	16-24 oz.	3	5	Joint line	3.3 to 5 oz.
4	49 oz.	3	7	Joint line	16.3 oz.
6	47 oz.	4	5	.003 offset	11.8 oz.

It should be noted that test sample 1 was used for setting up of the welding equipment and for tryout of the pull test fixture. Although the results of the pull test cannot be considered meaningful, it is still included among the test results. Test sample 3 broke at a lower value than expected. It is likely that the test sample was damaged slightly when removed from the epoxy glass board.

A proofmass assembly utilizing the Laser welded joints between the springs and supports was designed. If this pendulum displays a definite improvement in null bias stability at elevated temperature over the normal pendulum, then the deficiency must be in the epoxy spring joint. The design is further simplified to a degree that overshadowing influences arising from a shifting copper winding are eliminated. These shifts due to the different coefficient of expansion of copper against the bonding epoxy or that of the epoxy against the aluminum coil form are avoided. Since no copper winding is provided on the coil form, the necessity of an insulated pendulum support on one side is eliminated. The coil form which now conducts the con-



Laser Welded Proof Mass Assembly

Preliminary Design

Figure 5

strainment current is slit open on the lower side between the two supports. This forces the current to take a path only through the upper coil portion, which represents approximately three-quarters of a turn. To compensate for the lost strength from slotting, a stiffening web of .016 thickness was provided in the coil form center plane. This stiffener is a shunt to the useful current path, but the design reduces the useless current to tolerable limits. Approximately 80 to 120 ma current is expected to constrain this pendulum in the one g position. The supports are attached to the coil form in the conventional manner.

In order to provide the bend in the pendulum supports at the proper location, a bending fixture was designed. It consists of a locator pin to accept the inside diameter of the coil form and a precisely positioned forming block. The formed pendulum will be mounted to the standard assembly fixture which also accepts the baseplate and the springs. To hold the coil form tight to the fixture, a screw in the center plug of the fixture is normally used. Since, in this case, the center area is filled with the web stiffener, a special clamp with a hold down screw was designed.

The bending fixture and the special clamp for the pendulum alignment fixture have been manufactured and two coil forms as previously described have been produced. The supports have been attached to these foil forms in normal fashion and bent to the desired shape in the bending fixture. The supported coil forms were mounted and aligned to the standard pendulum assembly fixture using the special clamp to safely fasten the forms to the fixture. The surfaces on the outer edge, after performing the bend on the supports, were ground flat with a minimum amount of material removed to create a good alignment surface for the spring tab. Baseplate assemblies have been attached to the pendulum assembly fixture and the springs aligned in such a way that the gap between the spring tab and the ground surfaces of the pendulum support is .0005 inches. The spring tabs were bridged to the supports on the lower end of the support with a minimum of LCA-4 epoxy. These assemblies are now ready for Laser welding.

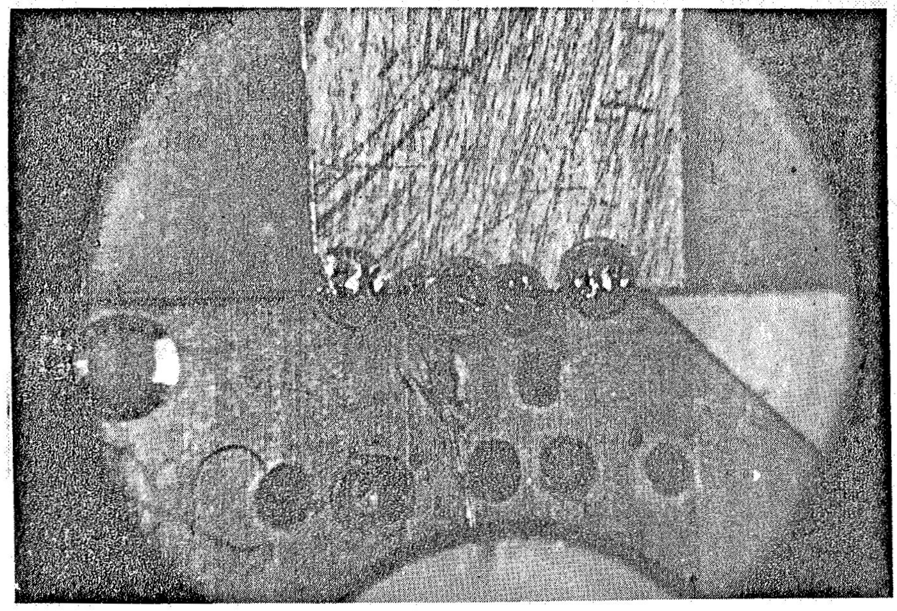


Photo 1. Group A Weld Sample 1 (20x mag.)

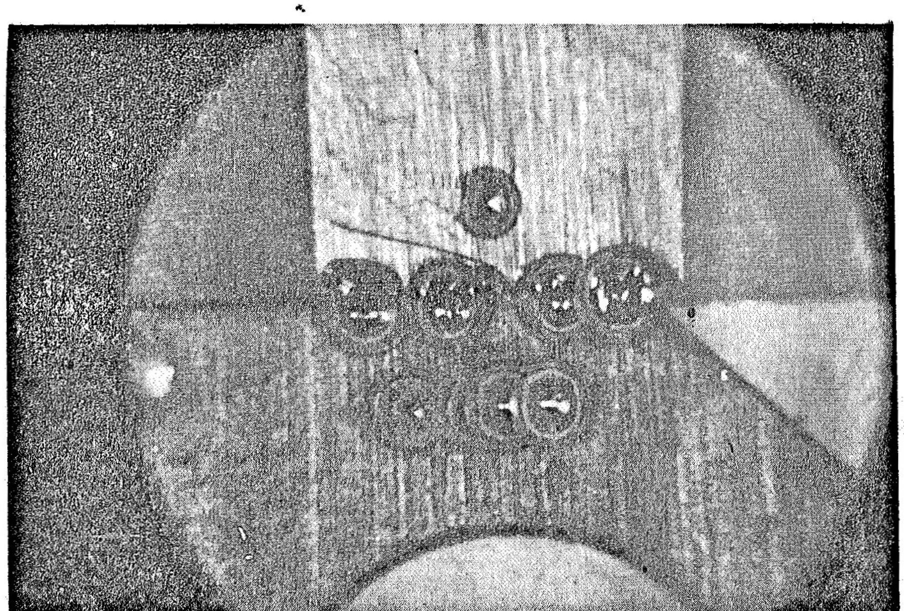


Photo 2. Group A Weld Sample 2 (20x mag.)

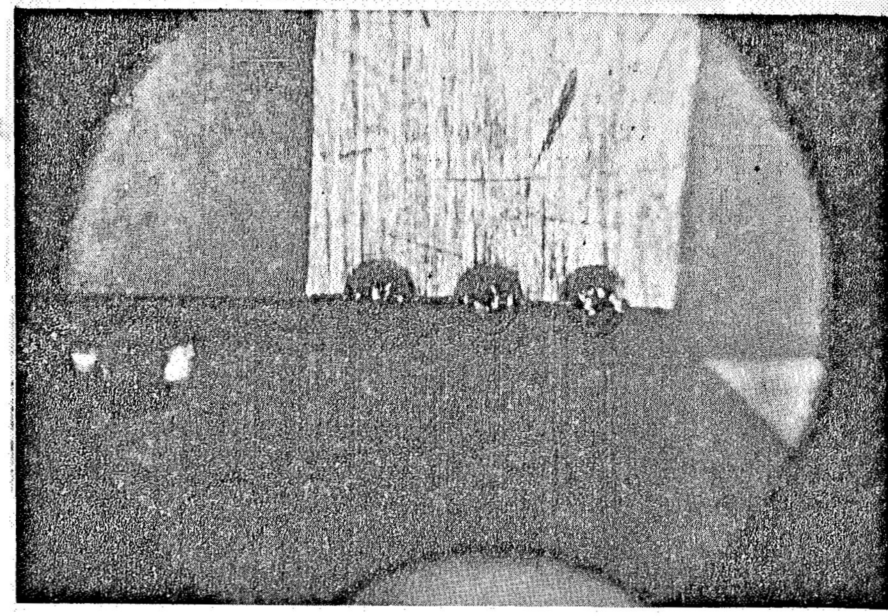


Photo 3. Group A Weld Sample 3 (20x mag.)

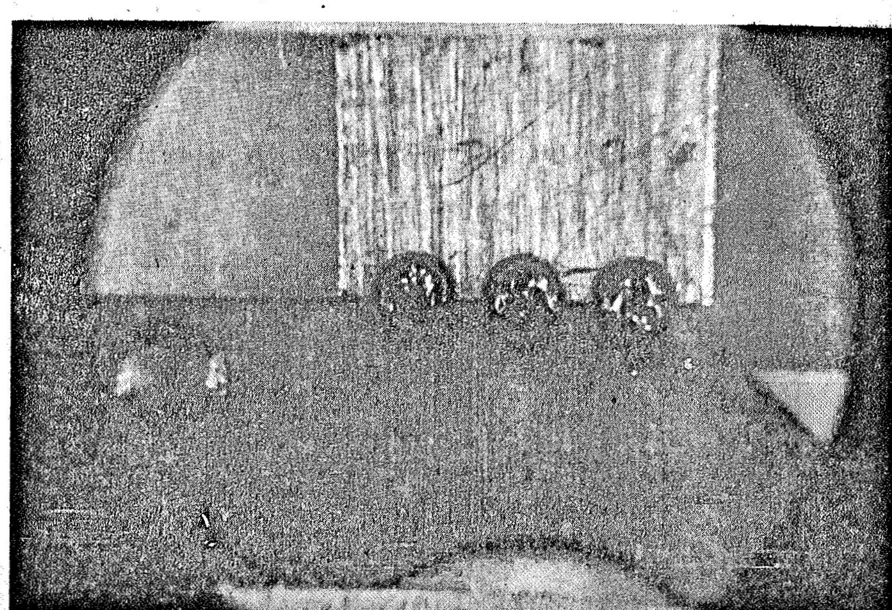


Photo 4. Group A Weld Sample 4 (20x mag.)

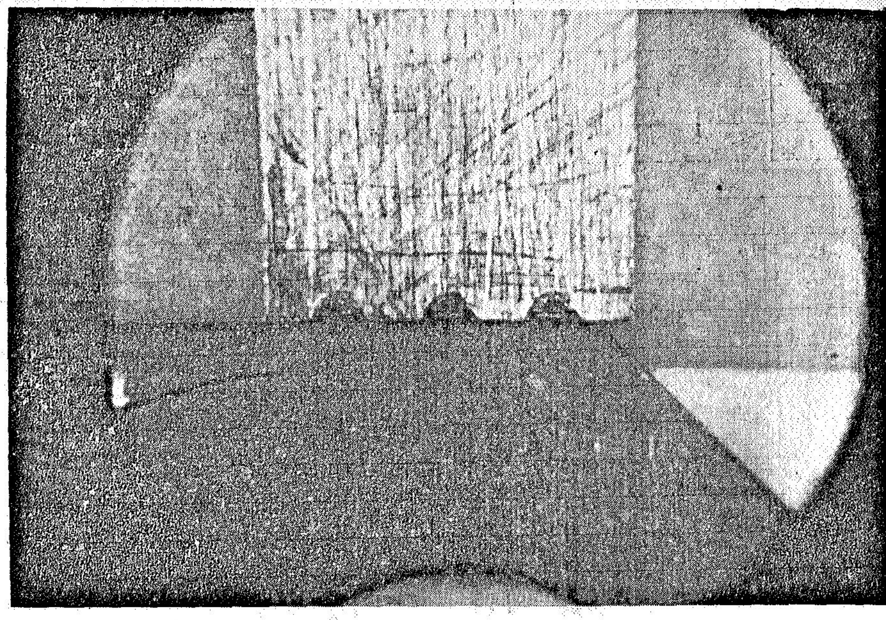


Photo 5. Group A Weld Sample 5 (20x mag.)

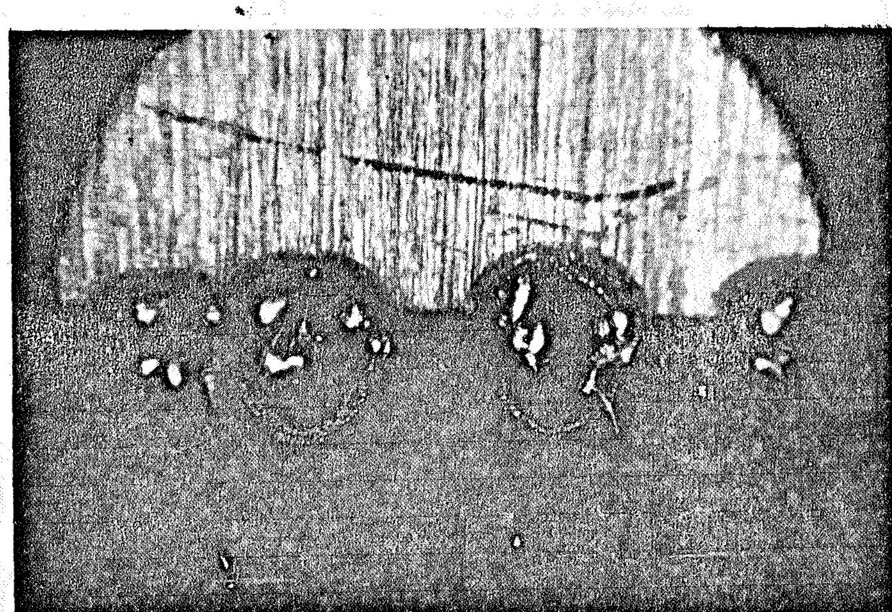


Photo 6. Group A Weld Sample 6 (55x mag.)

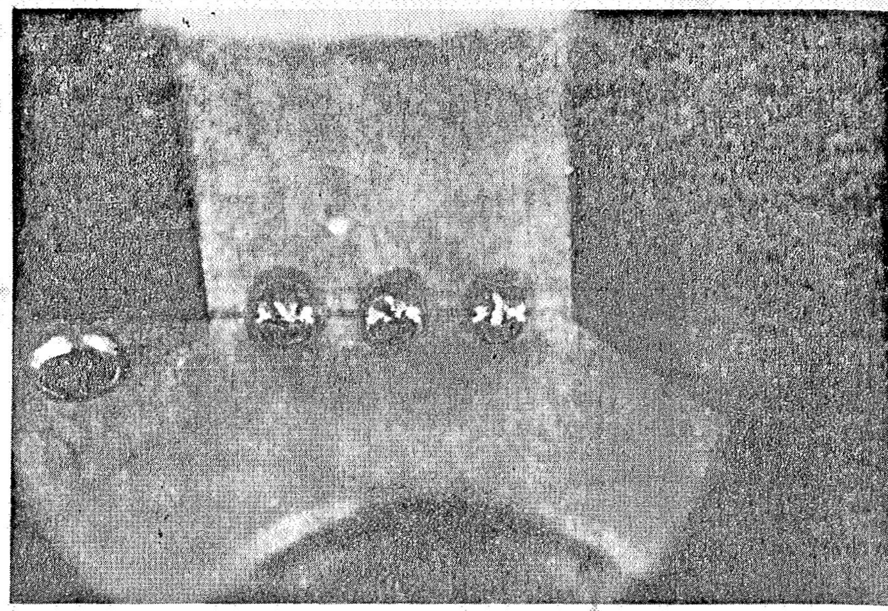


Photo 7. Group B Weld Sample 7 (20x mag.)

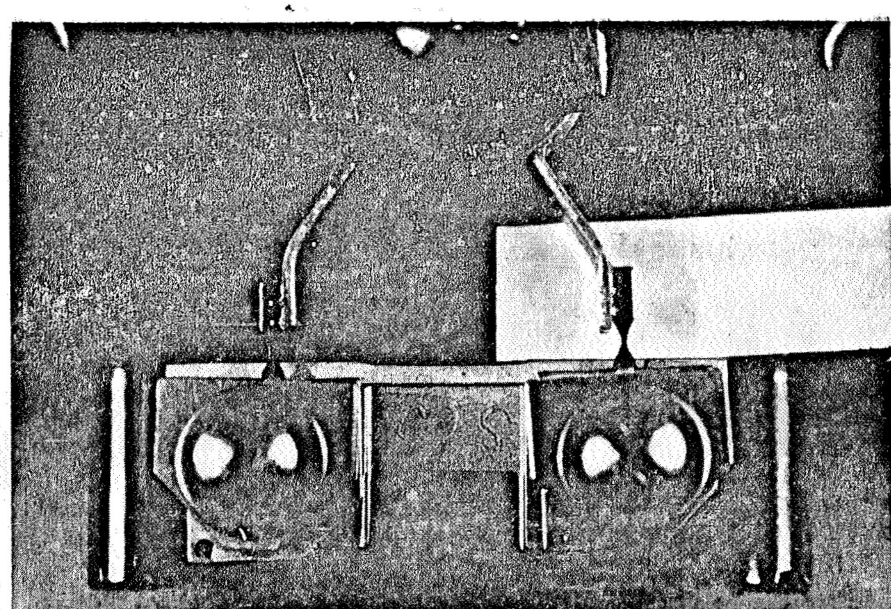


Photo 8. Group C Weld Samples 9 and 10 on Fixturing

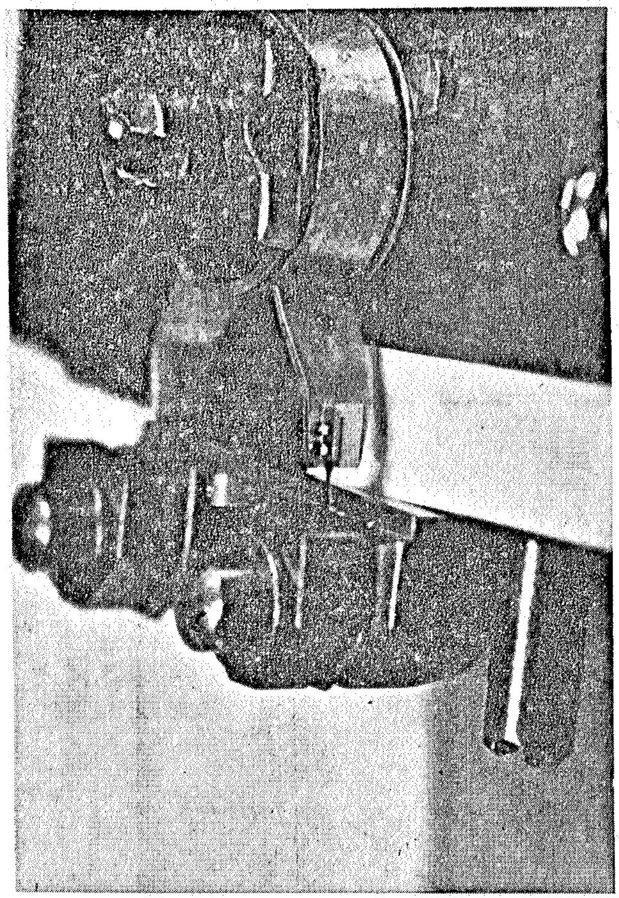


Photo 9.
Group C Weld Sample 10 on Fixturing

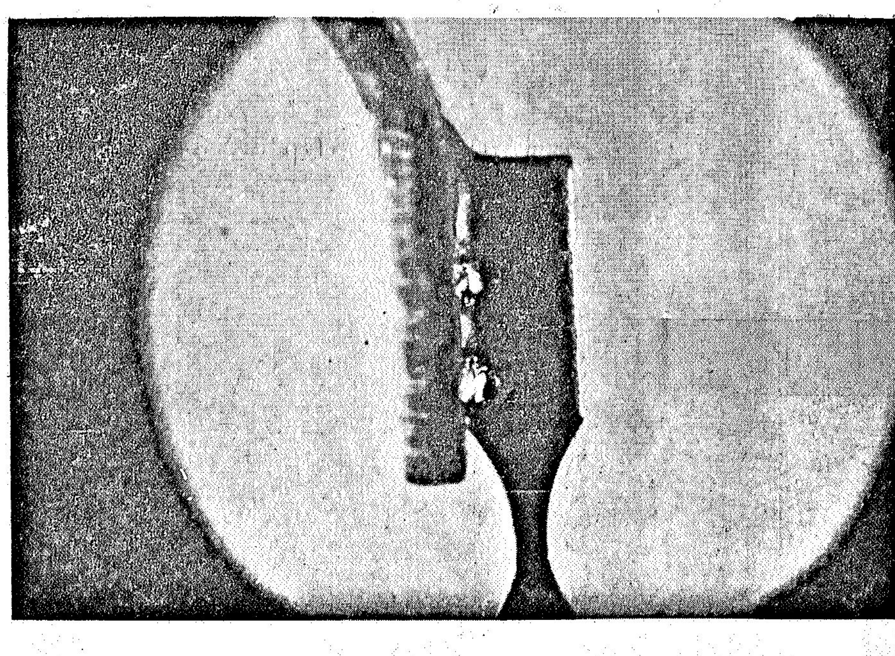


Photo 10. Weld Sample 10 (20x mag.)

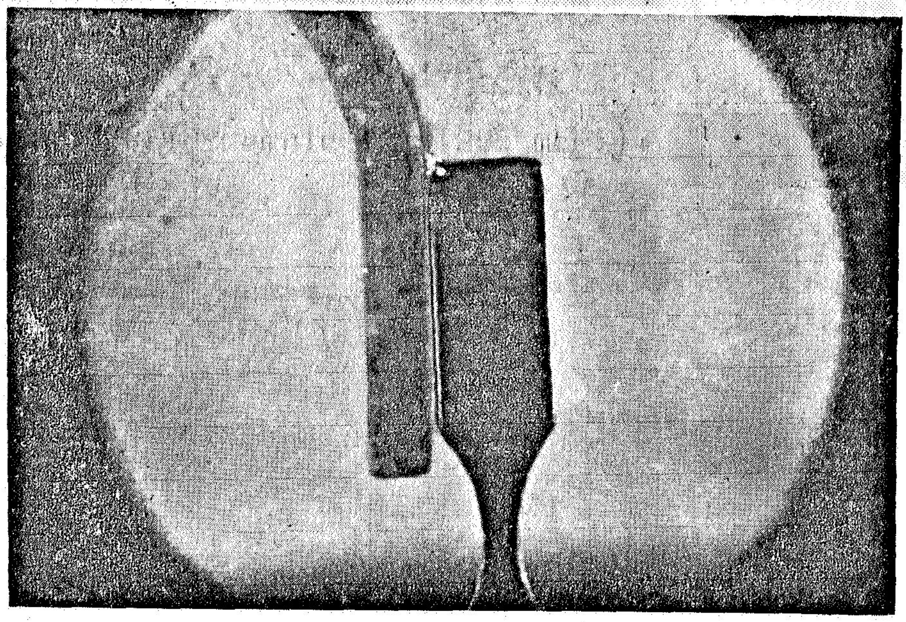


Photo 11. Weld Sample 12 (20x mag.)

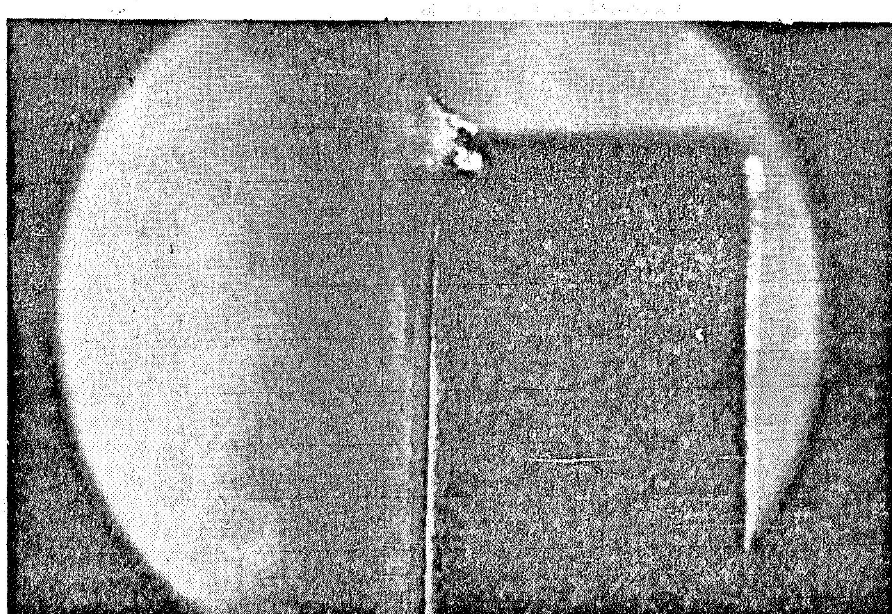


Photo 12. Weld Sample 12 (55x mag.)

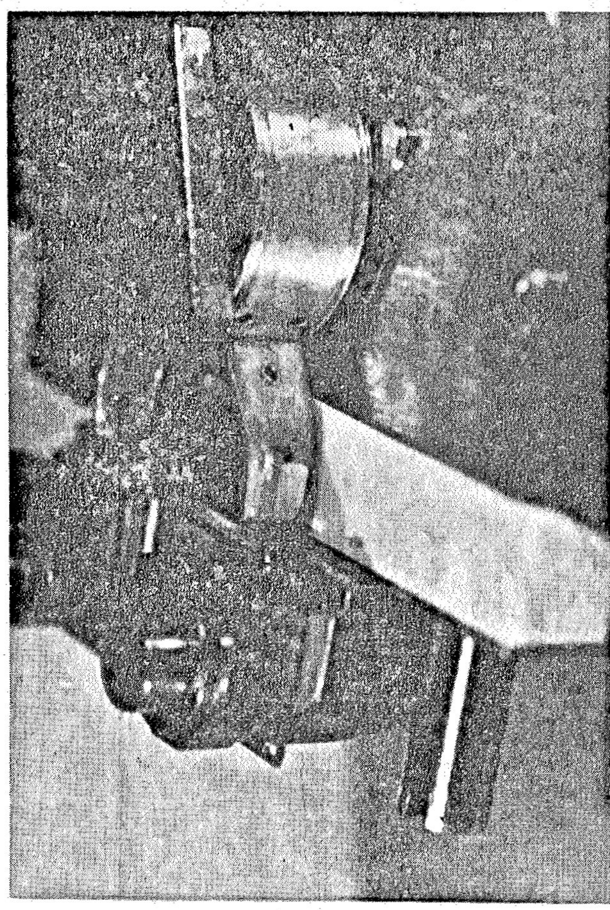


Photo 13.
Weld Sample 12
on Fixturing

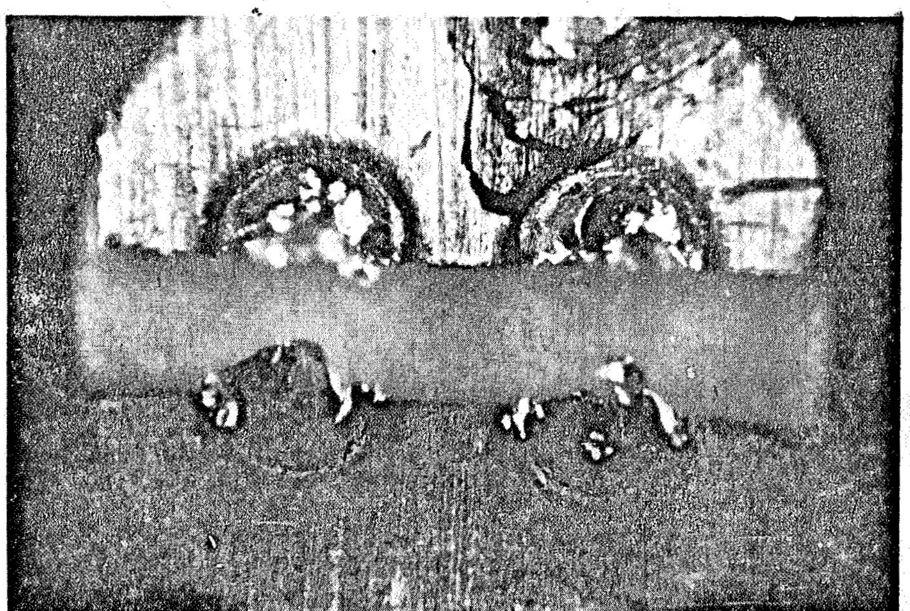


Photo 14. Pull Test on Typ. Group A Joint Line Weld

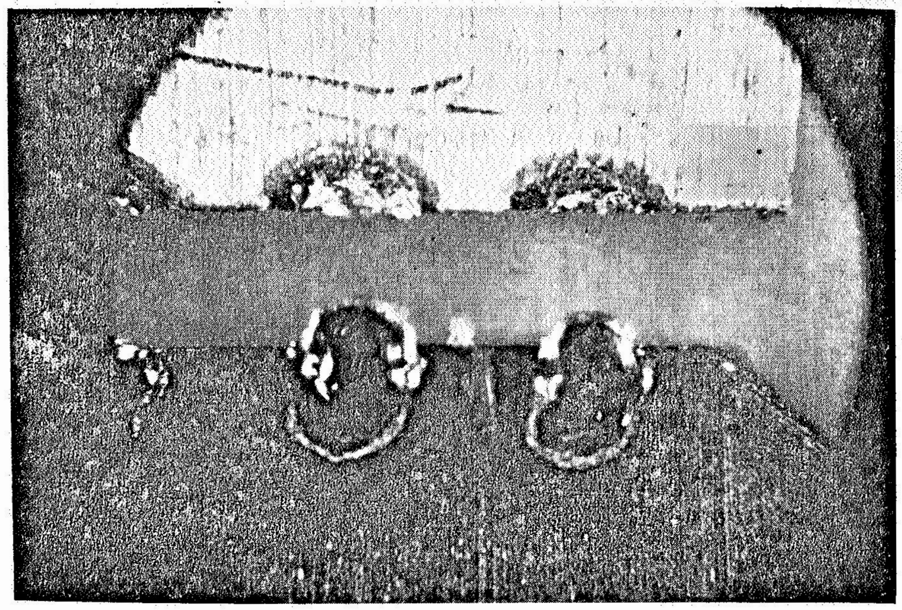


Photo 15. Pull Test on Group A Weld at .003 Offset

TRANSFORMERLESS ELECTRONICS

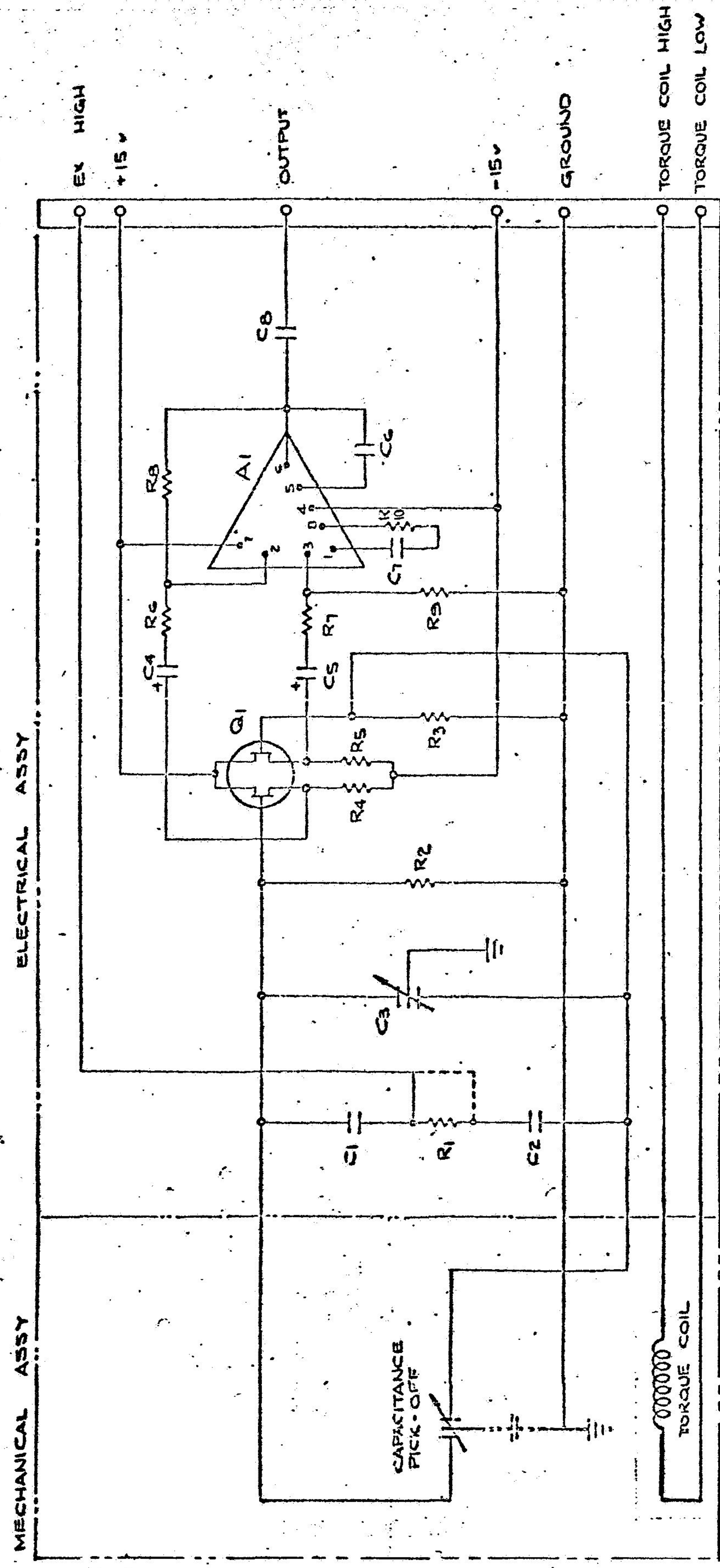
The transformerless bridge pickoff electronics was developed within the development efforts of the Model IX accelerometer. The design of the Model IX utilized discrete components and commercially available integrated circuits.

A matched pair of Amelco 2N3922 field effect transistors was used in conjunction with a UA709 operational amplifier. The A-C gain setting is about 100.

The testing and evaluation of the test results of the new design concept leads us to the following conclusions:

1. The 19pf input capacitances of the matched pair FET devices track in temperature extremely well.
2. The null drift of the electronics was found to be 0.0008pf/F°, which is well within the internal specification Bell set for bonnet null drift.
3. This design ensures better electrical null stability because it minimizes undesired stray capacitances in the critical bridge area and improves their stability because the input capacitance stability of FET devices is superior to stray capacitances of hand wound transformer windings.

The results encouraged us to recommend the design principle for other programs, including the Model VII accelerometer. A schematic showing the circuitry of the bonnet we are planning to deliver under the contractual requirements is included in this report. A detailed discussion of the new bonnet design will be a part of the next quarterly report.



SCHEMATIC OF TRANSFORMERLESS PICKOFF CIRCUIT

Figure 6